REDUCTION OF HEART SOUNDS FROM LUNG SOUND RECORDINGS BY AUTOMATED GAIN CONTROL AND ADAPTIVE FILTERING TECHNIQUES

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Abstract-**Auscultation is an attractive, simple, and noninvasive method for the diagnosis of cardiovascular and pulmonary disorders. However, heart sounds contaminates severely lung sound recordings. The results of our previous researches indicated that the Laplacian electrocardiographic signal (LECG) could be used as a reference for adaptive filtering to reduce heart sounds. In this paper, an integrated platform including an electronic stethoscope, an automated gain control (AGC), and an adaptive algorithm, has been developed to process the signal in real time. The AGC algorithm allows amplifying the LECG signal in different scales to solve the problem of relative weak LECG signals at right chest. The experimental result shows that the heart-noise reduction at right chest is improved from 43% reported early to 75%. The overall heart sound reduction by our new scheme ranges from 75% to 83% at different chest locations.**

Keyword: **Stethoscope, Auscultation, Adaptive Filtering, LECG**

I INTRODUCTION

In auscultation, heart sounds is an intrusive noise source in respiratory sounds. Simply using filtering technique cannot reject the unwanted signal, i.e. interference, effectively due to the overlapping in their spectra. Adaptive filtering may be the most suitable method to reduce intelligently the unwanted heart sounds in lung sound recordings. Nevertheless, adaptive scheme requires a "noise only" reference signal. In previous research [1], electrocardiographic (ECG) signal can be the reference signal, and this technique reduces the heart sounds by 50-80 percent. However, this technique requires at least two extra sensors to pick up the reference signal such as the lead II ECG. Another approach is to extract the "noise only" reference signal by a delayed version of original signal [2]. After the complex signal processing [3], a satisfactory result can be obtained. However, this scheme requires huge computation ability. Thus, it is difficult to implement those methods in a stethoscope for the real time applications.

In this work, Laplacian ECG (LECG) [4] is used for the 'noise only' reference signal rather than standard ECG. Both the electronic signal – Laplacian ECG, and the acoustic signal – lung sounds mixed with heart sounds can be picked up by a newly designed stethoscope. A simple adaptive filtering, least-mean-square (LMS) is used to eliminate the interference. All hardware and software designs have been integrated together to make a single device to process the signal in real time (Fig. 1).

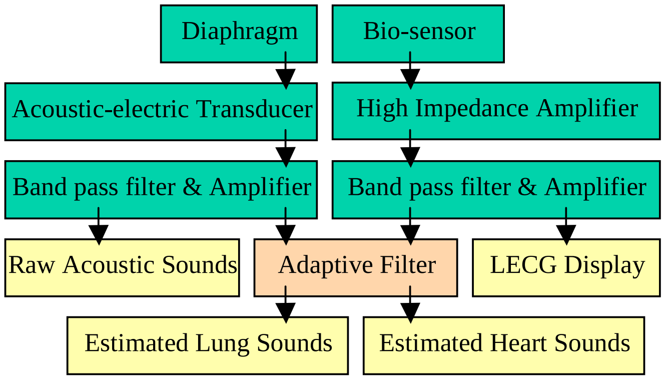

Fig. 1 Stethoscope block diagram

Using the new stethoscope, lung sounds without heart sound interference have been obtained successfully. Moreover, the LECG waveform can be observed at the same time.

II. SIGNAL PRE-PROPRESSING

Two different signals, acoustic signal and electronic signal are picked up by a new type stethoscope. Raw acoustic signal was band-pass filtered from 25Hz to 1000Hz. The operational amplifier (Linear Technology LT1013) was used with the gain factor of 40. Raw LECG was filtered by a band-pass filter with the bandwidth of 5Hz to 500Hz, and the gain factor of 1000. The high input impedance (10GΩ) of the amplifier (BURR-BROWN INA118 and LT1013) [5, 6] makes it insensitive to fluctuations of the skin-electrode impedance. Thus, the skin preparation before auscultation is not necessary. Both pre-processed signals are used as inputs to adaptive filtering

III. ALGORTHM & IMPLEMENTATION

The pre-processed signals were digitized by the Labview with a build-in analogue-to-digital converter at the sampling rate of 3000Hz. The algorithm was implemented on a Labview platform in IBM-compatible PC.

A) Automated Gain Control (AGC)

The pre-processed LECG can be used as a reference signal in adaptive filtering method. To make a good estimation of heart

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25OCT2001	N/A	-

Title and Subtitle Reduction of Heart Sounds from Lung Sound Recordings by Automated Gain Control and Adaptive Filtering Techniques	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Joint Research Center for Biomedical Engineering Department of Electronic Engineering, The Chinese University of Hong Kong, Shatin, N.T. Hong Kong	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research Development & Standardization Group (UK) PSC 803 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from the 23rd Annual International conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
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sounds, the amplitudes of the LECG signals should be kept constant from beat to beat at different locations. However, the strength of LECG signal in the human body is different from the left chest to the right chest. The signal acquisition at the left chest may be 10 times larger than that at the right side. The fluctuated heart sounds reduction on different auscultation locations in our previous research indicates the needs of a stable LECG signal [7].

Another problem in the LECG signal is over-amplification. It is difficult to adjust the gain factor manually in the LECG signal due to the amplitude variation in different chest locations. The over-amplified LECG signal will saturate the adaptive filter. As a result, the LMS algorithm may never converge to the minimum-mean-square error (MMSE).

The AGC algorithm (Fig. 2) amplifies the LECG signal in different scale according to the amplitude of the signal itself. The algorithm finds a maximum value among the data set to be a denominator. To smooth the signal, up to 3 denominators in 3 different data sets (present data set, last data set, and the data set before the last one) were founded, and stored in an array. The maximum value in the denominator array is a final denominator. All data in the present data set were divided by this value.

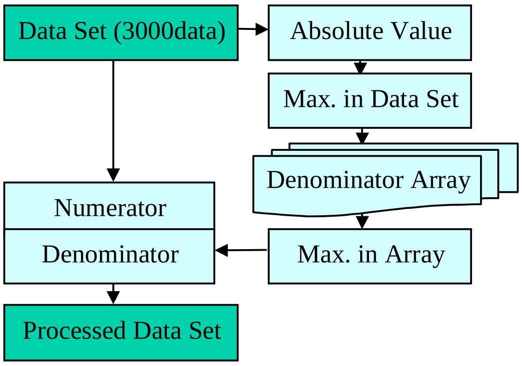

Fig. 2 Block diagram of the Automated Gain Control (AGC)

After the automatic gain control algorithm, the data set in different auscultation locations could be adjusted to a proper amplitude level as shown in Figure 3 and Figure 4.

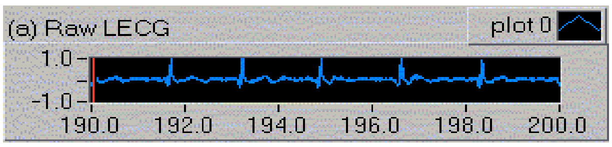

Fig. 3 Example of adjusted LECG signal at the left chest

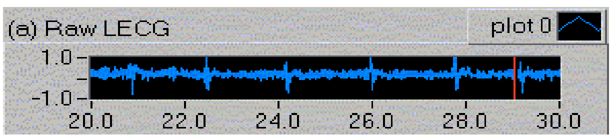

Fig. 4 Example of adjusted LECG signal at the right chest

B) Adaptive Filtering

In this research, a simple adaptive algorithm, the time-varying finite impulse response (FIR) filter of LMS algorithm was used [8]. The LMS algorithm updates the filter coefficients based on the method of steepest descent. It was noted that the LECG signal has only one spike corresponding to the first heart sound. To eliminate the effects corresponding to the first and second heart sounds, a FIR filter with 1000-taps was used to cover the time separation in both sounds. By trial and error, a proper value of step size is chosen to be 0.001.

IV. EXPERIMENTAL RESULTS

Four different locations of five male and healthy subjects were chosen for the experiments. The recording locations include top left, middle left, low left, top right, middle right, and low right of the front chest. Each collected signal with the length of 10 seconds was recorded to exam the reduction of heart sounds as shown in Figure 5.

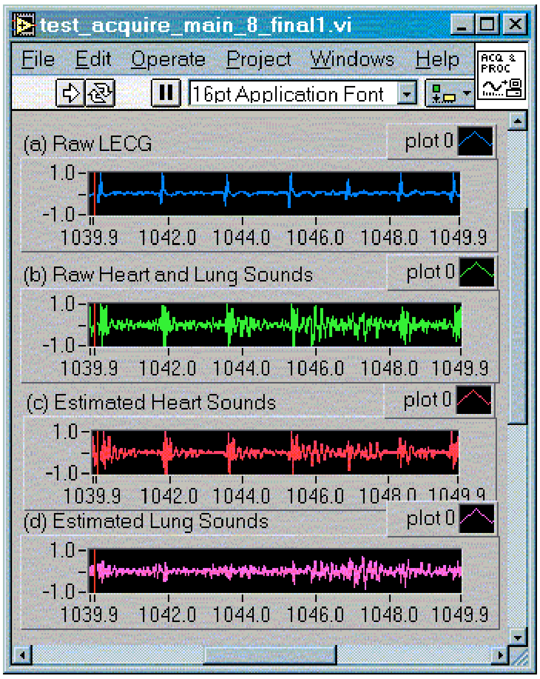

Fig. 5. Examples of signals: (a) Raw LECG, (b) Raw Heart and Lung Sounds, (c) Estimated Heart Sounds, and (d) Estimated Lung Sounds.

The estimated breath and heart sound are given in Fig. 5(c) and (d). It is clear that the heart sounds was almost removed completely. The average results of experiments at six locations on the five subjects are shown in Table.1. Heart sound reduction is from 75% to 83%. Only about 43% reduction of heart sound at right chest could be achieved early without the AGC algorithm [7], because the LECG signal from right chest was very weak. The heart sound reduction level is now similar at different locations after introducing AGC and adaptive algorithms. Among six testing locations, the middle right position is still the worst case in heart sounds reduction; even in this worst case, over 75% of heart artifacts reduction can be reached. The experimental results of each subject under the condition of holding breath are summarized in the same table for reference.

Table. 1.
Experimental Results

Location	Heart Sounds Reduction (normal breath)	Heart Sounds Reduction (holding breath)
Top left	82.76%	85.55%
Middle left	78.12%	82.88%
Low Left	80.54%	85.26%
Top right	78.37%	81.13%
Middle right	75.13%	80.23%
Low right	76.22%	82.97%

Note: heart sounds reduction equation (1) based on the energy difference between the estimated heat sounds and raw mixed sounds:

$$100\% - \left(\frac{\sum y^2 - \sum x^2}{\sum y^2} \times 100\% \right) \qquad (1)$$

where y is the component of raw mixed sounds and x is the component of estimated heart sounds.

V. CONCLUSION

For real-time auscultation, an AGC with adaptive algorithm has been implemented for electronic stethoscopes application. As a result, a convenient and effective heart sounds reduction electronic stethoscope has been proposed in this work. This scheme may facilitate the extraction and interpretation of the breath sounds.

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